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ESTIMATION OF SOLAR PANEL POWER FOR IRRIGATED CROPS IN NORTHERN GANGETIC PLAINS

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ABSTRACT

The irrigation requirement for different crops varies from climatic conditions and soil types. The energy required for irrigation was met by either electricity or diesel fuel, but it is highly costly, and it is not eco-friendly sources of energy. The solar energy is cheaper sources of energy which is ultimately pollution free. The average annual normal solar irradiance of Bihar is 4.37 kWh/m^2/day. The capacity of pump required to irrigate 1 ha of the field in the region of Pusa is 1 hp. The total power of the system calculated for 1.5 m^2, 0.75 performance ratio and panel yield 15% is 0.2 kW. For 1 ha field to irrigate, it requires four solar plates of 1.5 m^2.

The maximum solar panel power requirement estimated was 99.51 kW and 173.05 kW considering rainfall and without rainfall for 70 acres (28.35 ha). The carbon dioxide emissions mitigation will be 2829 tonnes by this installation and will be equivalent to planting 4,526 teak trees over the lifetime (data from IISc) for 99.51 kW. As well as, carbon dioxide emissions mitigation will be 4894.17 tonnes for this installation will be equivalent to planting 7,831 teak trees over the lifetime (data from IISc) for 173.05 kW. The break-even point (in years) for 70 acres (28.35 ha) field with electricity and diesel pump was 6.92 and 8.60 years using a pump of 32.82 hp. Moreover, for 1 ha field by electricity, and diesel pump was 6.92 and 8.60 years using a pump of 0.8775 hp up to a depth of 22m.

Thus, it will increase countries' energy security through reliance on an indigenous, inexhaustible and mostly import-independent resources, enhance sustainability, reduce pollution, lower the costs of mitigating climate change, and keep fossil fuel prices lower than other. These advantages are globally introduced and acceptable.

KEYWORDS: Solar Power, Irrigation, Crops, Gangetic Plains & Renewable Energy

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Original Article

INTRODUCTION

Agriculture is the crucial and backbone of Indian economy, and the primary input to biotic community. India is a prime agricultural country where about 54.6% (census 2010-11) of country's population based on agriculture, having a significant role in the socio-economic dignity. As per Economic Survey, agriculture is accounted for 17.4% of the GDP of the Indian economy in 2015-16. Several types of agricultural operations can be performed either by tractive work like seed-bed preparation, tillage, cultivation, harvesting, and transportation or by stationary work such as silage cutting, feed grinding, threshing, winnowing and irrigation water lifting. The pattern of energy consumption in agriculture has been changed substantially, with a major shifted from human and animal power to mechanical power like oil engines and tractors, and moving closer towards electrical power and renewable energy like solar energy, biogas, biomass and wind energy.

The use of energy in agricultural operations helps to improve the knowledge for farmers on how to

improve efficiencies and encourage to deploy renewable energy to improve the sustainability of agriculture. In India, the utility electricity sector had an as installed capacity of 304.761 GW (MNRE, 2016). Renewable power plants constituted 28% of total installed capacity. Renewable energy sector landscape in India has, during the last few years, witnessed a tremendous change in the policy to accelerate the plans to increase the contribution of solar energy. Solar energy has a prime role to play in energy security, helping achieve a clean energy mix in the country.

As far as agriculture is concerned, water is prime, natural, indispensable, finite and vulnerable resource. It is one of the most critical inputs, adequate and timely supply of which is necessary throughout the crop growing period. Water is supplied either by rainfall or through irrigation. Due to the inadequate and uneven distribution of rainfall during the growth period of crops, it becomes necessary to apply additional water to the soil in the form of irrigation for plant use. Irrigation consumes a significant amount of water and energy. Available irrigation water has to be utilized in a manner that matches the water needs of the crop. Supply of water above or below this is wasteful and quite injurious to agricultural productivity. The growth of agriculture has been possible because of timely and adequate supply of water as result ground water irrigation started assuming greater importance as compared to canal irrigation. Farmers have better control over water availability with groundwater irrigation in which water has to pump out which consume electrical energy.

Crops need water in significant quantities for their optimum growth. Excessive or deficit amounts of water could crimp down the growth of crop and climatically lower the crop’s yields. The various conditions influencing the rate of water use by crops include the type of crop, stage of growth, climatic parameters like temperature, wind velocity, humidity, sunshine, and so on, available water supply and soil characteristics and irrigation always associated with energy. Hence knowledge of water requirement of different crops and energy consumption to meet water requirement and scheduling is necessary for planning the farm irrigation system, in the design of irrigation projects and water resource development. During a recent year, Indian agriculture has experienced phenomenal growth in mechanization, and the energy needs have increased many times. A very conservative estimate reveals the requirement of about 68 billion kWh of electricity for Indian agriculture by the year 2020 (Panesar, 2000).

Electricity in the agricultural sector is used in pumping water for irrigating the land for operating farm machines and so on. The share of total electricity consumption by the agriculture sector increased from 81,673 GWh in 2001-02 (accounting for nearly 25% of the total electricity consumption in that year) to 133,660 GWh in 2011-12 (17.3% of the total consumption of electricity during that year) (CEA, 2013). Electrical energy consumption in agriculture was recorded highest 18.45% in 2014-15 (MNRE, 2016). The increased energy use in agriculture sector is directly associated with increased utilization of groundwater by irrigation pumping sets. The number of electrical pump sets has heightened faster, because of concerted efforts in rural electrification to promote groundwater utilization. The number of irrigation pumps (in 000’s) varies from 12,900 in 1990 to 28,000 in 2013 (CSAM-UNESCAP Regional meeting). Both, directly and indirectly, energy is used for irrigation. Electrical energy is directly used for pumping water from the tube well and pressuring an irrigation application system like a sprinkler, drip irrigation and so on. While, indirect energy is used to support on-farm irrigation application as well as used in the manufacture of irrigation equipment's, drilling of tube wells, leveling of fields and making and removing border ridges and furrows.

Irrigation is energy intensive operation. The energy requirement per hectare of irrigated land varies with the depth of pumped water, the type of irrigation system and the amount of water needed for crop growth (Khan et al., 2007). The energy needed to operate irrigation equipment is about five times that required for its manufacture (Stout, 1979). The

change in the cropping pattern in northern region has led to a sharp increase in the use of electricity during June to October to meet the irrigation demand of rice crop (Murthy and Raju, 2009). The consumption of electricity in the agriculture sector during these 4 to 5 months is as high as 60 percent of the total consumption during the whole year (Sindhy et al., 1987).

Energy resources are limited and sustainable agriculture will require increased use of energy resources. For sustainable agricultural development, irrigation ought to be planned and managed in such a way as to conserve both water and electricity. So the prediction of energy consumption with knowledge of water requirement is necessary for efficient utilization of water resources and energy which is critical to maximizing production and sustainability in agriculture. Since most of the farm operation is time-bound; any disturbances to the supply of energy for these operations affect the agricultural production. The increasing food demand created by the ever-increasing human population and uncertainty about energy availability further aggravate the problem of matching demand and supply. The agriculture sector occupies a significant position in the Indian economy as it provides livelihood and employment to over 58% of the population and contributes to around 14% of gross domestic product (MoA, 2016). Therefore, to avoid any adverse effect on the national economy, proper planning of energy requirements in the agricultural sector is very essential. These days mostly irrigation is carried out through either diesel pump set or electrical pump. Electricity obtained through fossil fuels as well as energy obtained from diesel engine increase the greenhouse gases in the atmosphere which causes threats to the environment and resulting in climate change which adversely affects the change in the rainfall pattern which ultimately reduces the production and productivity. The environmental and socio-economic problems can be significantly mitigated through the adoption of solar energy which is the cleanest form of energy and eco-friendly to the climate (Asaad M. Armanuos et al., 2016). Moreover, photovoltaic (PV) pumping system include low operating cost, unattended operation, low maintenance, easy installation, and long life and these are all important in remote locations where electricity may be unavailable (Aligah, 2011; Shinde et al., 2015).

METHODOLOGY

Description of the Study Area

The study was carried out for Pusa, located in the Samastipur district of north Bihar. Its latitude is $25^{.}98^{0}$ N; longitude is 85.67^{0} E, and about 52 m above mean sea level. Climate is sub-humid and sub-tropical with reasonably good rainfall during monsoon. According to meteorological data recorded at Agro meteorological Observatory, Pusa (Bihar), average maximum and minimum temperature were 26.8°C and 17.0°C respectively. Daily sunshine hours, Average wind speed and average daily evaporation were 4.0 hours, 1.2 km/hr, and 1.3 mm respectively as well as the average relative humidity was 89 percent at 0700 hrs and 52 percent at 1400 hrs. Soil temperature at 5 cm depth was 16.5°C at 0700 hrsand 22.8^{o}C at 1400 hrs.

Application of CROPWAT 8.0

According to Smith & Kivumbi (2002), CROPWAT is a computer program for irrigation planning and management which was developed by the Land and Water Development Division, FAO (FAO, 1992). Its primary functions include the calculation of reference evapotranspiration, crop water requirements, and crop and scheme irrigation. CROPWAT is a practical tool to assist agro-meteorologists, agronomists and irrigation engineers to hold out the standard calculation of evapotranspiration and crop water use studies, and a lot of especially the planning and management of irrigation schemes (Sandhu, 2003). The computerized program can easily access databases for climate and crop

characteristics to allow for speedy determination of irrigation water requirements. Input required in this software includes three types of data: to figure out irrigation scheduling, demands meteorological data, crop data and soil data in the program. FAO recommended using CROPWAT software to better estimation of CWR under various scenarios of climatic changes (FAO, 2009). It has been widely used in assessing CWR and scheduling crops (Smith, 1991; Smith &Kivumbi, 2006). It follows the FAO approved Penman-Monteith method better to predict ET_o, ET_c and irrigation water requirement (FAO, 1998; Smith, 1991; Kang et al., 2009).

Equations Used in Calculation of Energy Requirement

- **Irrigation Water Requirements**

From the original Penman-Monteith equation and the equations of the aerodynamic and surface resistance, the FAO Penman-Monteith method to estimate $ET_o$is expressed as:

$$ET_O = \frac{0.408\,\Delta\,(R_n - G) + \gamma\frac{900}{(T+273)}u_2(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34u_2)} \tag{1}$$

Crop evapotranspiration can be determined from climatic data and by integrating the crop resistance directly, reflective power and air resistance factors in the FAO Penman-Monteith approach. As there is still a substantial lack of information for various crops, the Penman-Monteith method is employed for the estimation of the standard Reference crop to calculated its evapotranspiration rate, i.e., Reference evapotranspiration (ET_o). Experimentally determined ratios of ET_c/ET_o referred to as Crop coefficient (K_c), are used to relate Crop evapotranspiration beneath standard conditions (ET_c) to ET_o. This method is popular as the crop coefficient approach (Allen et al., 2006; Tyagi et al., 2000; Kingra et al. 2004; Karetal, 2007) which is depends mainly on weather variables i.e., temp., relative humidity, wind speed, sunshine hours, rainfall etc. (Sentelhas et al., 2010).

$$ET_c = K_c * ET_o \tag{2}$$

Albedo, air temperature, humidity and wind speed are all integrated for the ET_o estimation. Therefore, ET_o corresponds to climatic demand index, while K_c value varies primarily with the distinct crop nature and only to a certain measure with climatical conditions and soil evaporation, enables the transfer of standard K_c values between locations and between climates. TheK_c in the equation above allows ET_c prediction. The ET_c predicted by Kc is adjusted if necessary to non-standard conditions through the Crop evapotranspiration under nonstandard conditions (ET_cadj) where any environmental condition or characteristic is known to have an impact on or to limit ET_c.

The crop coefficient values, K_c helps in the estimation of CWR, ET_o, ET_c at different growth stage and eventually, K_c values has been explored relatively in India for irrigation water management of a location (Tyagi et al., 2000; Tripathi, 2004; Kingra et al., 2004; Kar et al., 2007). Since Kc values vary with location, native climate, topographic conditions, water table situations and management practices (Doorenbos & Kassam, 1979; Allen et al., 2006), therefore several studies across different agro-ecological regions of India have been conducted to derive growth stages basis K_c values of crops using lysimeter and / or field water balance approach (Tyagi et al., 2000; Tripathi, 2004; Kingra et al., 2004; Kar et al., 2007).

- **Rainfall**

The quantity of the rainfall to our field or location the option effective rainfall method for CWR calculations are

USDA Soil Conservation Service formula developed by USCS, where effective rainfall can be calculated according to monthly step:

$$Peff = P_{month} * (125 - 0.2 * P_{month}) / 125 \text{ for } P_{month} <= 250 \text{ mm} \quad (3)$$

$$Peff = 125 / 3 + 0.1 * P_{month} \text{ for } P_{month} > 250 \text{ mm} \quad (4)$$

Rainfall not considered in irrigation calculations (Effective rainfall = 0): Choosing this option makes CROPWAT ignore rainfall data during the calculations of irrigation requirements.

- **Yield Reduction**

Yield reduction due to soil moisture stress is represented as a percentage of the maximum production achievable in the area under optimal conditions. It can be computedconcerning a single stage of crop cycle or the whole growing season. Yield reduction is expressed applying the following equation:

$$(1 - \frac{y_a}{y_m}) = K_y(1- \frac{ET_Q}{ET_m}) \quad (5)$$

This approach and calculation procedures for estimating yield response to water (FAO Irrigation & Drainage Paper No. 33, Doorenbos and Kassam, 1979)

- **Irrigator's Equation**

For the estimation of the amount of water applied to a field, the Irrigator's Equation can be used to calculate the volume of water applied. In the equation:

$$Q * t = d * A \quad (6)$$

Where, Q is the flow rate, in Acre-mm/month; t is the total time of irrigation, month; d is the depth of water applied, mm; and A is the area irrigated, acres.

Volume of water applied in field (m^3) = flow rate (m^3/sec) X total time of duration (sec)

Energy Requirements for Irrigation Operation

The amount of energy required to pump water for irrigation depends on the net amount of irrigation water to be applied, i.e., the total dynamic head (depth of water table, drawdown friction losses in pipes and fittings, seasonal fluctuation in the water table, delivery head requirements), and pump efficiency and efficiency of energy conversion of the power unit. The amount of energy required to lift given amount of water by tube-well is

$$E = MgH / (3600 \text{ X } 1000)$$

$$E = Q\rho gH / (3600 \text{ X } 1000) \quad (7)$$

Where,

E = Energy input (kWh);

m = Mass of water pumped out (kg);

Q = volume of water pumped out (m^3);

P = mass density of water (kg/m^3);

g = acceleration due to gravity (ms^{-2}) and H = total head (m).

$$E = (Q*1000*9.81*H) / (3600*1000)$$

$$E = 2.725\ Q*H*10^{-3} \quad (8)$$

Combining the pump, electric motor, application and conveyance efficiencies, the energy requirements for irrigation operation becomes

$$E_t = (2.725\ Q* H*10^{-3} / \text{Irrigation efficiency}) \quad (9)$$

Where, E_t = Total energy requirements for irrigation operation

- **Solar Power Requirements for Irrigation Operation**

The solar panel power, P in kilowatts (kW) is equal to the energy E in kilowatt-hours (kWh) and divided by the consumption period in hours.

$$P\ (kW) = E\ (kWh) / t\ (hr) \quad (10)$$

Where t (hr) is in average sunshine hours over a month

- **Cost Involvement in Solar Panel Installation System**

The cost determination of solar power requirements for irrigation operation month wise, which is selected according to the maximum power used in that particular month for a particular crop. MNRE (GoI), provides Solar Rooftop Calculator in which input variables are installation capacity (kW), average electricity cost/kWh, the category of customer (Residential, Institutional, Industrial and commercial), subsidy 30% based on MNRE scheme, debt-equity ratio (0:100, optional), cost of solar plant Rs. 75,000 / kW (based on MNRE benchmark). It gives the cost of a plant with subsidy and without subsidy, total electricity generation annually and lifetime (25years), tariff @ Rs.7.15 / kWh (for a top slab of traffic). No increase assumed over 25 years (monthly, annually and lifetime-25years), carbon dioxide emissions mitigated and how much its installation will be equivalent to planting (data from IISc). However, we are much interested in installation cost of a plant with subsidy and without subsidy, Carbon dioxide emissions mitigated, and installation will be equivalent to planting.

- **Electricity Cost Estimation**

The cost of electricity can be calculated by multiplying the electricity cost per kWh of total units consumed (kWh). As per Electricity Department of DRPCAU, Pusa 1 unit (kWh) cost for irrigation is Rs 7.15. As per Indian Petroleum, 1-liter diesel fuel cost is Rs 62.40.

- **Break Even Point Analysis**

The break-even point (BEP) in economics, business, and individually cost accounting, is the point at which there is no net loss or gain. Total profit at the break-even point is zero.

Here, Break-even point (in years) = (Total installation cost)/(Consumption cost per year)

RESULTS

Irrigation Water Requirements

The amount of irrigation water required to fulfill the irrigation water requirements of the crop estimated by using FAO Penman-Monteith method. The estimates for the components of this equation presented and discussed in the following sections. The average monthly irrigation requirements (000' m^3) in different crops from 2010-11 to 2015-16) determined by calculating the average of monthly irrigation requirements year wise year shown below in Figure 1 and Figure 2. The volume of water required in 70 acre area was maximum in rice crops followed by maize (Kharif) in both cases of irrigation considering rainfall and without rainfall.

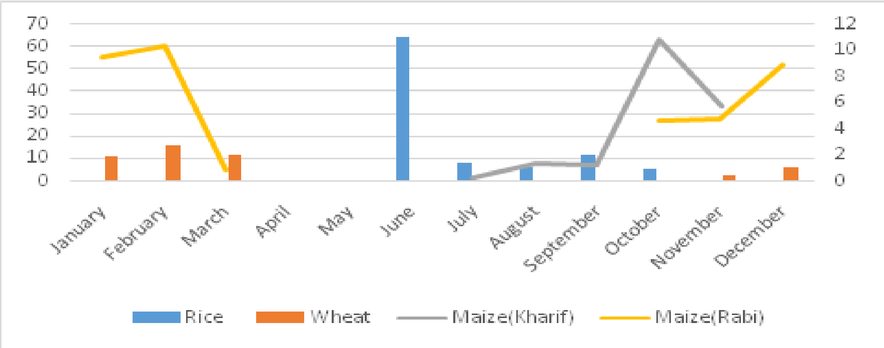

Figure 1: Month-wise Average Volume of Water Required (000' m^3) for Irrigation Considering Rainfall From 2010-11 to 2015-16

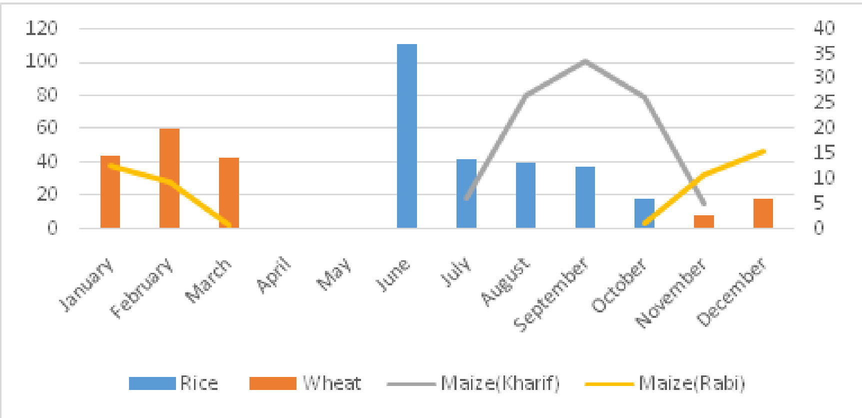

Figure 2: Month-wise Average Volume of Water Required (000' m^3) for Irrigation Considering No Rainfall From 2010-11 to 2015-16

Electricity Requirement for Irrigation Operation

Based upon climatological parameters for the year 2010-11 to 2015-16. The electricity required for irrigation for Pusa form was calculated. The results are presented in Figure 3 and Figure 4 considering rainfall and no rainfall maximum electricity requirement in irrigation for Pusa farm were 15200.31 and 26434.57 kWh respectively for irrigated crops of 70 acres land. This difference might be due to varying crops, maximum and minimum temperature, RH, wind speed, rainfall and sunshine hours.

Figure 3 and Figure 4 also show that electricity requirement in June was much higher than other months July, August, September, and October in the case of Rice considering rainfall and no rainfall. The electricity requirement in

January was much higher than other months November, December, February, and March in case of Wheat considering rainfall and no rainfall. The electricity requirement in August was much higher than other months July, September, October, and November in case of maize (Kharif) considering rainfall and no rainfall. The electricity requirement in December was much higher than other months October, November, January, February, and March in case of maize (Rabi) considering rainfall and no rainfall. This is due to high water requirements of rice crop to meet its evapotranspiration. Also, electricity requirements for irrigation during these four months were as high as 57 percent of the requirements during the year.

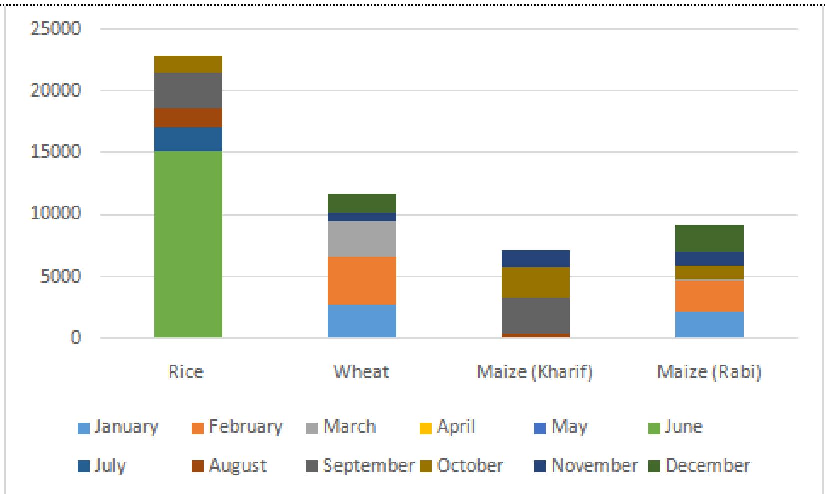

Figure 3: Month-wise Estimation of Average Energy Requirements for Irrigation Operation Considering Rainfall From 2010-11 to 2015-16 (in kWh)

Table

Month	Rice	Wheat	Maize (Kharif)	Maize (Rabi)
January	0	2701719.684	0	2239322.672
February	0	3923768.93	0	2442777.358
March	0	2898568.698	0	208739.2226
April	0	0	0	0
May	0	0	0	0
June	15200310.92	0	0	0
July	1930837.809	0	52845.3728	0
August	1552993.393	0	310466.5652	0
September	2841099.355	0	2884036.221	0
October	1417577.125	0	2549789.238	1085311.844
November	0	708788.5627	1337648.499	1123624.739
December	0	1446642.08	0	2099282.434

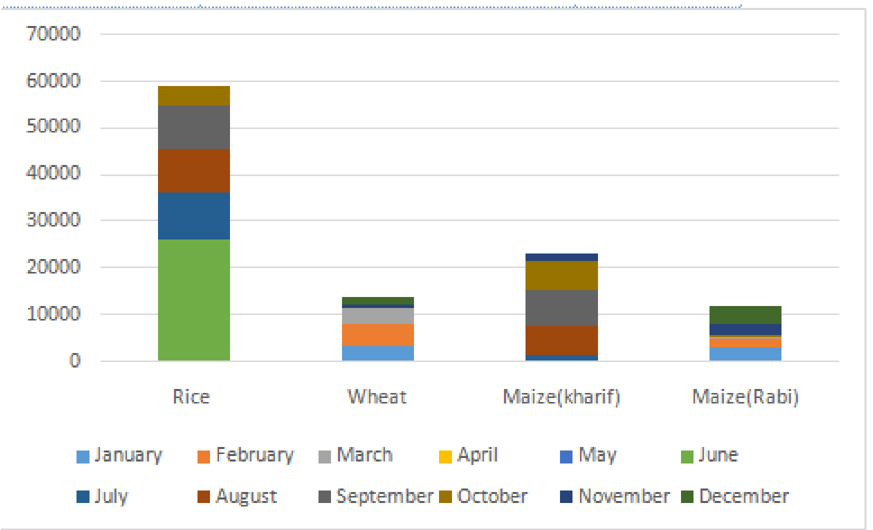

Figure 4: Month-wise Estimation of Average Energy Requirements for Irrigation Operation Considering No Rainfall From 2010-11 to 2015-16 (in kWh)

Solar Power Requirements for Irrigation Operation

The solar panel power P in kilowatts (kW) is equal to the energy E in kilowatt-hours (kWh), divided by the consumption period in hours for irrigated crops of 70 acres.

Table 1: Month-wise Estimation of Average Solar Power Requirements for Irrigation Operation Considering Rainfall from 2010-11 to 2015-16 (in 10^{-3} kW)

Month	Rice	Wheat	Maize (Kharif)	Maize (Rabi)
January	0.0	40025.47	0.0	33175.15
February	0.0	28640.64	0.0	17830.49
March	0.0	16103.15	0.0	1159.66
April	0.0	0.0	0.0	0.0
May	0.0	0.0	0.0	0.0
June	99511.04	0.0	0.0	0.0
July	14544.92	0.0	398.081	0.0
August	14412.93	0.0	2881.36	0.0
September	19661.59	0.0	19958.72	0.0
October	8710.151	0.0	15666.90	6668.58
November	0.0	5693.08	10744.16	9025.09
December	0.0	23618.64	0.0	34273.99

Table 2 Month-wise Estimation of Average Solar Power Requirements for Irrigation Operation Considering No Rainfall From 2010-11 to 2015-16 (in 10^{-3} kW)

Month	Rice	Wheat	Maize(Kharif)	Maize(Rabi)
January	0.0	51573.16	0.0	44527.11
February	0.0	35448.79	0.0	16765.58
March	0.0	19183.54	0.0	896.95
April	0.0	0.0	0.0	0.0
May	0.0	0.0	0.0	0.0
June	173057.8	0.0	0.0	0.0
July	75302.17	0.0	10802.94	0.0
August	87115.17	0.0	58577.44	0.0
September	62207.6	0.0	54710.50	0.0
October	26739.27	0.0	37909.04	1339.39
November	0.0	5693.08	9762.59	20724.29
December	0.0	23737.27	0.0	60696.68

Cost Involvement in Solar Panel Installation System

The cost determination for solar power requirements for irrigation operation month wise which is selected according to the maximum power used in that particular months for a particular crop. The MNRE (GoI) provides Solar Rooftop Calculator within which input variables are installation capacity (kW), average electricity cost (Rs/kWh), the category of customer (Residential, Institutional, Industrial and commercial), Subsidy 30% based on MNRE scheme, the debt-equity ratio (0 : 100, optional), cost of solar plant Rs 75,000 / kW (based on MNRE benchmark).

Table 3: Cost Estimation of Maximum Month Wise Solar Power Requirements for Irrigation Operation Considering Rainfall

Month	Power (Wp)	Institutional / Commercial Price (In Rs.)	Price With Subsidy 30 % (In Rs.)
January	40.02 (Wheat)	3,000,000	2,100,000
February	28.64 (Wheat)	2,175,000	1,522,500
March	16.10 (Wheat)	1,200,000	840,000
April	0	0	0
May	0	0	0
June	99.51 (Rice)	7,500,000	5,250,000
July	14.54 (Rice)	1,125,000	787,500
August	14.41 (Rice)	1,125,000	787,500
September	19.95 (Maize Kharif)	1,500,000	1,050,000
October	15.66 (Maize Kharif)	1,200,000	840,000
November	10.74 (Maize Kharif)	825,000	577,500
December	34.27 (Maize Rabi)	2,625,000	1,837,500

Table 4: Cost Estimation of Maximum Month Wise Solar Power Requirements for Irrigation Operation Considering Without Rainfall

Month	Power (Wp)	Institutional/Commercial Price (in Rs.)	Price With Subsidy 30 %(in Rs.)
January	51.57 (Wheat)	3,900,000	2,730,000
February	35.44 (Wheat)	2,625,000	1,837,500
March	19.18 (Wheat)	1,425,000	997,500
April	0	0	0
May	0	0	0
June	173.05 (Rice)	12,975,000	9,082,500
July	75.30 (Rice)	5,625,000	3,937,500
August	87.11 (Rice)	6,525,000	4,567,500
September	62.20 (Rice)	4,725,000	3,307,500
October	37.90 (Maize Kharif)	2,850,000	1,995,000
November	20.72 (Maize Rabi)	1,575,000	1,102,500
December	60.69 (Maize Rabi)	4,575,000	3,202,500

It gives the cost of a plant with subsidy and without subsidy, total electricity generation annually and lifetime (25years), tariff @ Rs.7.15 / kWh (for a top slab of traffic). Moreover, no increase assumed over 25 years (monthly, annually and lifetime-25years), carbon dioxide emissions mitigated and how much its installation will be equivalent to the planting of Teak trees (data from IISc). However, we are much interested in installation cost of a plant with thesubsidy, and without subsidy, Carbon dioxide emissions mitigation, and installation will be equivalent to planting.

Break-even Point Analysis

The maximum average power calculated by taking the average of all maximum power through different crops in

different months (taken from Table 3 & Table 4). The irrigation of different crops covering 70 Acres (28.35 ha) from a single pump is not a right decision because it is not economically profitable. To establish solar power plant for 24.49kW which is the average throughout years, it requires a large area for its establishment. The break-even point (in years) was 6.92 years for the cost of electricity @7.15 per unit of electricity. Moreover, break-even point (in years) was 8.60 years for diesel fuel price @ Rs 62.40/Ltr.

Design of Solar PV Panel for 1 ha Field

The average solar power required for 1 ha was 0.877575kW. The annual average solar irradiance for Bihar is 4.37 kWh/m^2/day. Using the Global formula, E = A * r * H * PR. Taking total solar panel area = 1.5 m^2, performance ratio = 0.75 and solar panel yield = 15%. The total power of the system is 0.2kWp. Thus, to install solar PV panel for irrigation of 1 ha area of the field, it requires four solar PV plate of 1.5 m^2 area to be installed.

CONCLUSIONS

In the present study, information on rainfall, climatic parameters, cropping system, crop yields, water table depth below ground surface, area cultivated under different crop were obtained from different departments and used to calculate the electricity requirement for irrigation operation of Pusa farm. The development of affordable, inexhaustible and clean solar energy technologies will have substantial longer-term benefits which would increase countries energy security through replacing an indigenous, inexhaustible and mostly import-independent resource. Moreover, finally enhance sustainability, reduce pollution, lower the costs of mitigating climate change, and keep fossil fuel prices lower than other energy. These advantages are globally introduced and acceptable.

Based on the results of the study, the following conclusions could be drawn:

- The maximum and minimum groundwater required for irrigation operation of Pusa farm were 64212.20 m^3 and 223.24 m^3 respectively considering rainfall as well as 111670.20 m^3 and 669.72 m^3 respectively considering no rainfall for 70 acres of land.
- The average energy and solar panel power requirements for irrigation was maximum in June in rice crop in comparison to other crops in other months considering rainfall and without rainfall.
- The maximum solar panel power requirement estimated was 99.51 kW and 173.05 kW considering rainfall and without rainfall for 70 acres of land.
- The estimated cost of solar panel installation system considering rainfall and without rainfall for maximum solar panel power was Rs. 7,500,000 and Rs. 12,975,000 without subsidy for 70 acres of land.
- The Carbon dioxide emissions mitigation will be 2829 tonnes, and this installation will be equivalent to planting 4,526 Teak trees over the lifetime (Data from IISc) for 99.51 kW. As well as Carbon dioxide emissions mitigation will be 4894.17 tonnes, and this installation will be equivalent to planting 7,831 Teak trees over the lifetime (Data from IISc) for 173.05 kW.
- The break-even point (in years) for 70 acres (28.35 ha) field by electricity and diesel pump was 6.92 and 8.60 years by using a pump of 32.82 HP up to a depth of 22m.
- The break-even point (in years) for 1 ha field by electricity and diesel pump was 6.92 and 8.59 years by using a

pump of 0.8775 HP up to a depth of 22m.

- For the 1 ha field to irrigate, it requires four solar plates of 1.5 m^2.

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